Preface

The main aim of the work reported in this thesis is to improve the precision of atomic measurements by combining the advantages of laser cooled atoms with those of spectroscopy techniques. We apply these ideas to experiments for measuring atomic signatures of discrete symmetry violations in the laws of physics. For example, measuring EDM of atoms would act as a testing ground for theories beyond the Standard Model. The Standard model predicts EDMs which are too small to be measured, but theories beyond Standard model predict values of EDM within experimental reach. This thesis describes laser cooling and trapping of ytterbium atoms using its two cooling transitions and the launching of the cooled atoms in an atomic fountain. Developing the atomic fountain has been an important component of this thesis since using a fountain of atoms instead of a thermal atomic beam increases the precision of EDM measurements.

The thesis is organized as follows. In Chapter 1, we describe the motivation and advantages of the laser cooling and trapping of Yb. We also discuss the importance of frequency measurements in the precise determination of atomic parameters such as hyperfine structure and isotope shift. Knowledge of these parameters is important in high-precision atomic calculations necessary to interpret the results of experiments in terms of the fundamental laws of physics.

In Chapter 2, we describe the different theoretical aspects of light-atom interactions, which includes the creation of dressed states and the force of light on atoms. We discuss the role of dressed-state interference in causing EIT in the three types of three-level systems – lambda (Λ), ladder (Ξ), and vee (V). We also develop the theory of hyperfine structure and isotope shift of atoms. Finally we discuss the theory of laser cooling and trapping of atoms, using the force of near-resonant light on atoms.

In Chapter 3, we describe the realization of three-level ladder system using $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 7S_{1/2}$ transition in ^{85}Rb. The first experiment using this system deals with the rotation of the plane of polarization of a laser beam passing through this medium. The rotation occurs because the medium behaves differently for the two orthogonally-polarized components, displaying what is known as circular birefringence or linear dichroism. In the presence of both a control laser and magnetic field, the lineshape shows an interesting interplay between the two effects with regions of suppressed and enhanced rotation. Next, we describe the phenomenon of EIT in the same system under conditions of a strong probe beam. Density-matrix analysis of the system shows that, for zero-velocity atoms, the strong probe beam causes a reduction in absorption and broadening of the profile. But the lineshape after thermal averaging shows a splitting of the EIT resonance and enhanced absorption near line center. The experimental observations agree qualitatively with the predicted lineshapes.

In Chapter 4, we describe the experimental design and apparatus used for laser cooling experiment of Yb. First, we discuss design of the Yb atomic beam source. Next, we describe the design and implementation of the Zeeman slower. Then we discuss the design of the two vacuum chambers used in the experiment; the first for the atomic fountain and the second for the magnetic trapping. Finally, we describe the details of the lasers used to different transitions and the spectroscopy on these transitions.

In Chapter 5, we describe precision frequency metrology of optical transitions. First, we describe the absolute frequency measurement of $5P_{3/2} \rightarrow 7S_{1/2}$ transition in ^{87}Rb using the two-step excitation $5S_{1/2} \rightarrow 5P_{3/2}$ and $5P_{3/2} \rightarrow 7S_{1/2}$. Determining the frequency of $5P_{3/2} \rightarrow 7S_{1/2}$ transition allows us to determine the absolute frequency of the important $5S_{1/2} \rightarrow 7S_{1/2}$ two-photon transition, since the frequency of $5S_{1/2} \rightarrow 5P_{3/2}$ is known. Our values are consistent with earlier frequency-comb measurements of the two-photon transition. In the next section, we describe the frequency measurement of various spectral components in the 555.8 nm $^1S_0 \rightarrow {}^3P_1$ line of Yb. The isotope shifts are determined with 60 kHz precision, an order-of-magnitude improvement over the best previous measurement on this line. There are two overlapping transitions,

^{171}Yb$(1/2 \rightarrow 3/2)$ and ^{173}Yb$(5/2 \rightarrow 3/2)$, which we resolve by applying a magnetic field.

In Chapter 6, we describe laser cooling and trapping of Yb. We describe Zeeman slowing of Yb atomic beam using the $^1S_0 \rightarrow ^1P_1$ blue transition. Next, we describe a MOT on the same transition, which we refer to as the blue MOT. We then discuss the loading of a MOT using the intercombination line $^1S_0 \rightarrow ^3P_1$, which we call the green MOT. Loading of the green MOT is done either by transferring atoms from the blue MOT or directly from the Zeeman-slowed beam. Next, we describe the magnetic trapping of Yb in the $^3P_2$ metastable state in a spherical quadrupole field. In the last section, we discuss launching of the Yb atoms from the green MOT in a fountain.

In Chapter **??**, we describe future work about search for a permanent atomic EDM and other experiments which can be performed in Yb.